

We claim:

1    1. A method for forming a metal pattern in a substrate, the  
2    method comprising the steps of:

3        depositing a lower hardmask layer on the substrate, the  
4        lower hardmask layer having a dielectric constant less than  
5        about 4.5;

6        depositing a middle hardmask layer on the lower hardmask  
7        layer;

8        depositing a top hardmask layer on the middle hardmask  
9        layer, the top hardmask layer having a thickness less than  
10      about 200 Å;

11      forming a first opening in the top hardmask layer in  
12      accordance with a first pattern, thereby exposing a portion of  
13      the middle hardmask layer;

14      forming a second opening in said portion of the middle  
15      hardmask layer in accordance with a second pattern and a  
16      corresponding opening in the lower hardmask layer, thereby  
17      exposing a portion of the substrate;

18      forming an opening in the substrate;

19      depositing metal in the opening in the substrate; and  
20      removing the top hardmask layer.

21      2. A method according to claim 1, wherein the top hardmask  
22      layer is of a material selected from the group consisting of  
23      refractory metals, refractory metal nitrides, refractory metal  
24      alloys, doped amorphous silicon and doped silicon.

25      3. A method according to claim 1, wherein the middle hardmask  
26      layer is of a material selected from the group consisting of  
27      SiO<sub>2</sub>, SiN, SiON and SiOF.

1       4. A method according to claim 1, wherein the lower hardmask  
2       layer is of a material selected from the group consisting of  
3       SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,  
4       silicon oxycarbide, amorphous hydrogenated silicon carbide and  
5       amorphous hydrogenated silicon carbide/nitride.

1       5. A method according to claim 1, wherein said step of  
2       depositing metal further comprises depositing excess metal  
3       overlying the top hardmask layer, and further comprising the  
4       step of removing the excess metal by polishing the metal in a  
5       chemical-mechanical polishing (CMP) process, a polishing rate  
6       of the top hardmask layer being less than a polishing rate of  
7       the metal.

1       6. A method according to claim 1, wherein said step of forming  
2       the first opening includes depositing a resist layer on the top  
3       hardmask layer and subsequently removing the resist layer  
4       therefrom, and wherein the middle hardmask layer protects the  
5       lower hardmask layer from oxidation during removal of the  
6       resist layer.

1       7. A method for forming a metal pattern in a substrate, the  
2       substrate having a dielectric constant less than about 4, the  
3       method comprising the steps of:

4           depositing a lower hardmask layer on the substrate, the  
5       lower hardmask layer having a dielectric constant less than  
6       about 4.5;

7           forming a protective layer in a region of the lower  
8       hardmask layer adjacent to a top surface thereof;

9           depositing a top hardmask layer on the lower hardmask  
10      layer, the top hardmask layer having a thickness less than  
11      about 200 Å;

12 forming a first opening in the top hardmask layer in  
13 accordance with a first pattern, thereby exposing a portion of  
14 the lower hardmask layer;

15 forming a second opening in said portion of the lower  
16 hardmask layer in accordance with a second pattern, thereby  
17 exposing a portion of the substrate;

18 forming an opening in the substrate;

19 depositing metal in the opening in the substrate; and  
20 removing the top hardmask layer.

1 8. A method according to claim 7, wherein the material of said  
2 top hardmask layer is selected from the group consisting of  
3 refractory metals, refractory metal nitrides, refractory metal  
4 alloys, doped amorphous silicon and doped silicon.

5 9. A method according to claim 7, wherein the lower hardmask  
6 layer is of a material selected from the group consisting of  
7 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,  
8 silicon oxycarbide, amorphous hydrogenated silicon carbide and  
9 amorphous hydrogenated silicon carbide/nitride.

10. A method according to claim 7, wherein said step of  
11 depositing metal further comprises depositing excess metal  
12 overlying the top hardmask layer, and further comprising the  
13 step of removing the excess metal by polishing the metal in a  
14 chemical-mechanical polishing (CMP) process, a polishing rate  
15 of the top hardmask layer being less than a polishing rate of  
16 the metal.

1 11. A method according to claim 7, wherein  
2       said step of forming the first opening includes depositing  
3       a resist layer on the top hardmask layer and subsequently  
4       removing the resist layer therefrom, and

5       said step of forming a protective layer comprises exposing  
6       the lower hardmask layer to a plasma, thereby forming a  
7       protective nitride layer in said region which protects the  
8       lower hardmask layer from oxidation during removal of the  
9       resist layer.

1 12. A method according to claim 7, wherein  
2       said step of forming the first opening includes depositing  
3       a resist layer on the top hardmask layer and subsequently  
4       removing the resist layer therefrom, and

5       said step of forming a protective layer comprises exposing  
6       the lower hardmask layer to a plasma which densifies the lower  
7       hardmask layer in said region, so that the protective layer  
8       protects the lower hardmask layer from oxidation during removal  
9       of the resist layer.

1 13. A method according to claim 7, wherein  
2       the lower hardmask layer is deposited under conditions  
3       such that the material of the lower hardmask layer has  
4       increased density in said region adjacent to the top surface of  
5       the lower hardmask layer.

1 14. A method according to claim 7, wherein  
2       said step of forming the first opening includes depositing  
3       a resist layer on the top hardmask layer and subsequently  
4       removing the resist layer therefrom, and

5       the resist layer is removed in a non-oxidizing resist  
6       strip process.

1 15. A method according to claim 7, wherein the protective  
2 layer has a thickness of approximately 100 Å.

1 16. A method for forming a metal pattern in a substrate, the  
2 substrate having a dielectric constant less than about 4, the  
3 method comprising the steps of:

4 depositing a lower hardmask layer on the substrate, the  
5 lower hardmask layer having a dielectric constant less than  
6 about 4.5;

7 depositing a top hardmask layer on the lower layer, the  
8 top hardmask layer having a thickness less than about 200 Å;

9 forming a first opening in the top hardmask layer in  
10 accordance with a first pattern, thereby exposing a portion of  
11 the lower hardmask layer;

12 forming a second opening in said portion of the lower  
13 hardmask layer in accordance with a second pattern, thereby  
14 exposing a portion of the substrate;

15 forming an opening in the substrate;

16 depositing metal in the opening in the substrate; and  
17 removing the top hardmask layer,

18 wherein said step of forming the first opening further  
19 comprises depositing a resist layer on the top hardmask layer  
20 and subsequently removing the resist layer therefrom, and

21 the resist layer is removed in a non-oxidizing resist  
22 strip process.

1 17. A method according to claim 16, wherein the material of  
2 said top hardmask layer is selected from the group consisting  
3 of refractory metals, refractory metal nitrides, refractory  
4 metal alloys, doped amorphous silicon and doped silicon.

1 18. A method according to claim 16, wherein the lower hardmask  
2 layer is of a material selected from the group consisting of  
3 SiC:H, SiCOH, SiCNH, carbon-doped oxide, organosilicate glass,  
4 silicon oxycarbide, amorphous hydrogenated silicon carbide and  
5 amorphous hydrogenated silicon carbide/nitride.

1 19. A method according to claim 16, wherein said step of  
2 depositing metal further comprises depositing excess metal  
3 overlying the top hardmask layer, and further comprising the  
4 step of removing the excess metal by polishing the metal in a  
5 chemical-mechanical polishing (CMP) process, a polishing rate  
6 of the top hardmask layer being less than a polishing rate of  
7 the metal.

20. A method according to claim 16, wherein the resist strip process is a plasma process with a reducing chemistry.

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